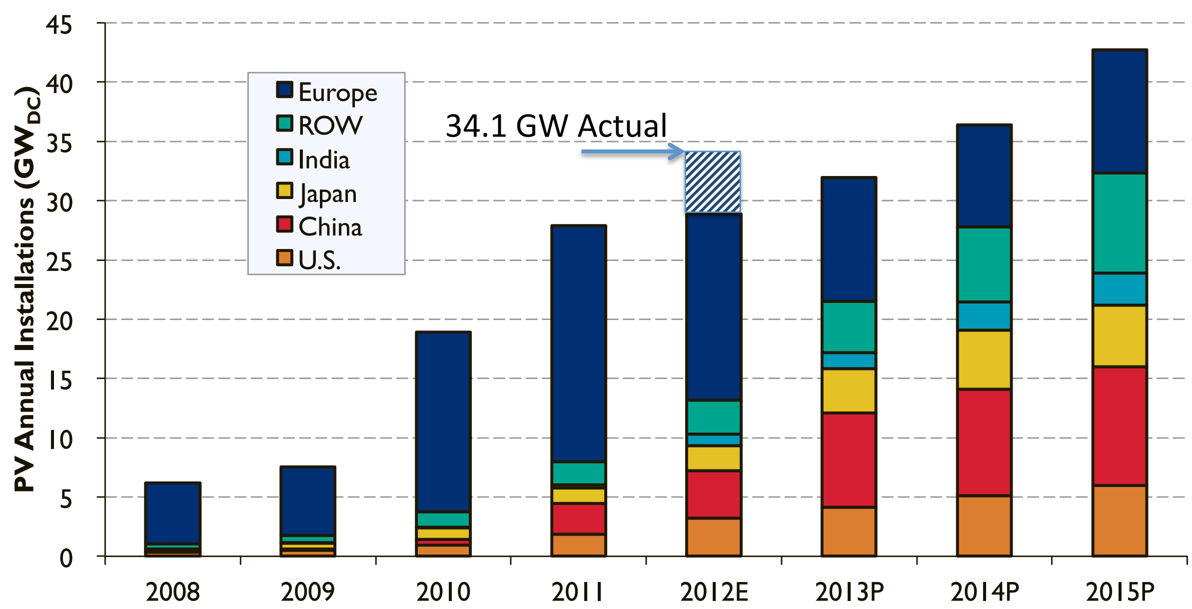
Where are the Frontiers of Energy Research in a Stormy World?

The March of Solar is Triumphant and Unstoppable

Don't Worry, Be Happy



> 100 GW global PV installed capacity

=8-10 nuclear reactor/year

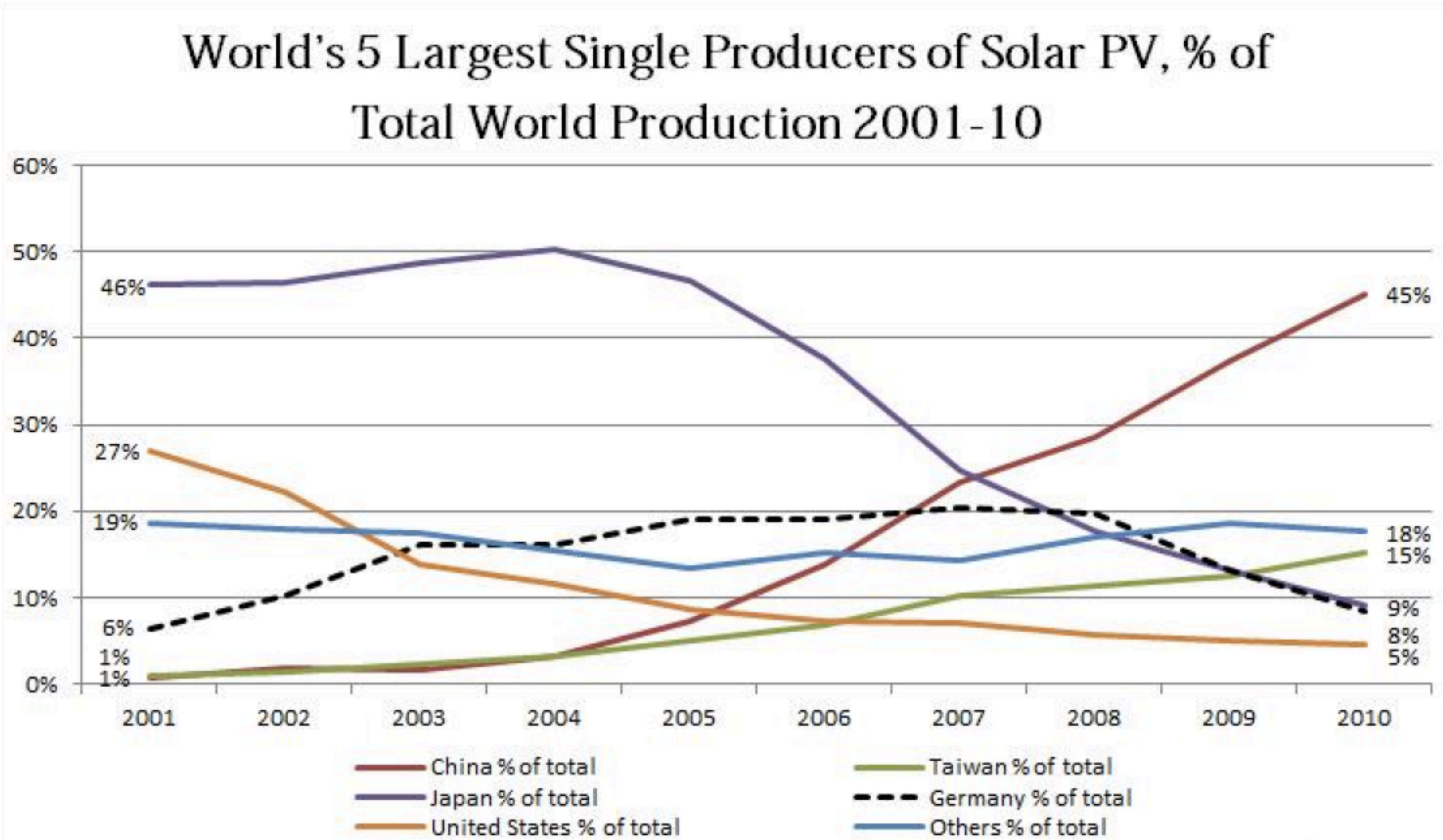
But Seismic Shifts Are Emerging in the Deep

Don't Happy, Be Worry

1. Global geographical shifts from US/Japan to China
2. Huge and unpredictable price fluctuations
3. Business models: large fluctuations and shifts
4. Huge and unpredictable technology shifts
5. Huge shifts in government subsidies
6. Huge and unpredictable changes in competing energy sectors

Energy research has to recognize and adapt to the shifts of its environment more than regular academic research

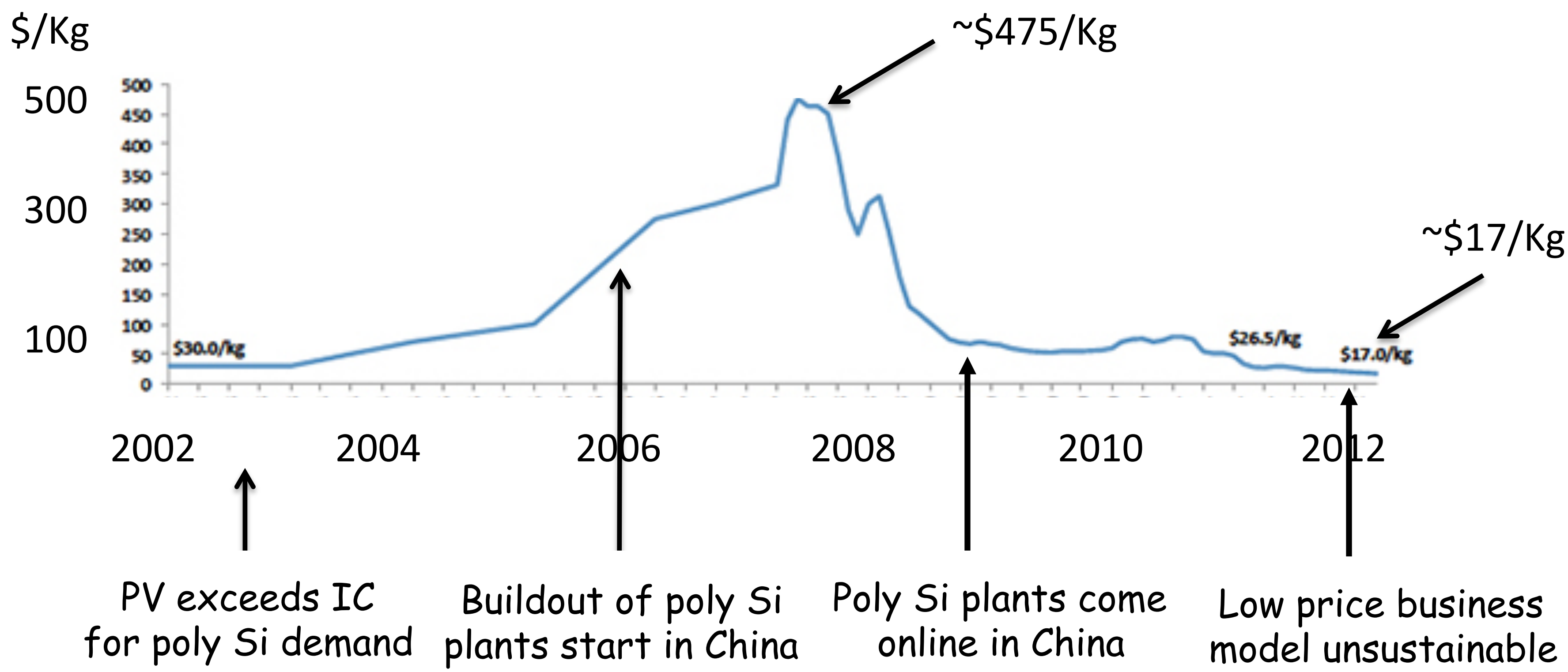
1. Top 10 Solar Companies: The Baton Passes from US/Japan to China



1. Top 10 Solar Companies: The Baton Passes from US/Japan to China

Solar Cell Company	Country	2009 shipment(MW)	2010 shipment(MW)
Suntech	China	704	1572
JA Solar	China	520	1464
First Solar	USA	1100	1411
Yingli Solar	China	525.3	1062
Trina Solar	China	399	1057
Motech Solar	Taiwan	360	924
Q-Cells	Germany	586	907
Gintech	Taiwan	368	827
Sharp	Japan	595	774
Sungen Solar	China	193	588
Source	Photon	PVinsights	

2. Huge Price Fluctuations



3. Business Models: Shifts and Fluctuations

Company	Status
Suntech	Bankrupt
Konarka	Bankrupt
Evergreen	Bankrupt
Solibro	Bankrupt
Solyndra	Bankrupt
Nanosolar	Reorganizing
Sharp	Shrinking
Applied Materials	Exited PV
First Solar	Doing well

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But First Solar is doing well because it left manufacturing for installation

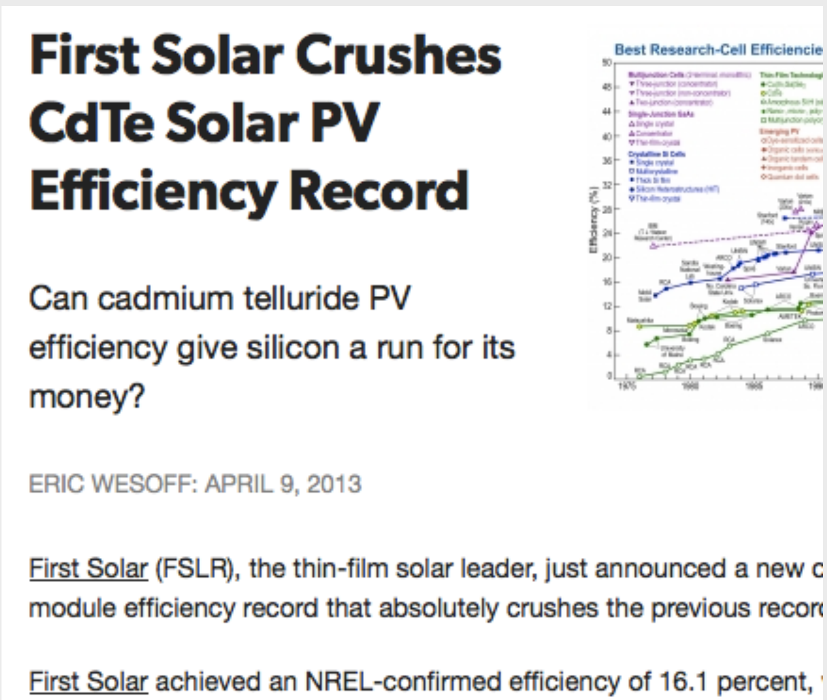
3. Business Models: Shifts and Fluctuations

Year	Number of Car companies
1913	127
1970	3

Shifts and fluctuations do not necessarily mean the demise of an industry

4. Huge Technology Shifts

Thin Films Won!



First Solar Crushes CdTe Solar PV Efficiency Record

Can cadmium telluride PV efficiency give silicon a run for its money?

ERIC WESOFF: APRIL 9, 2013

First Solar (FSLR), the thin-film solar leader, just announced a new c
module efficiency record that absolutely crushes the previous recor

First Solar achieved an NREL-confirmed efficiency of 16.1 percent,

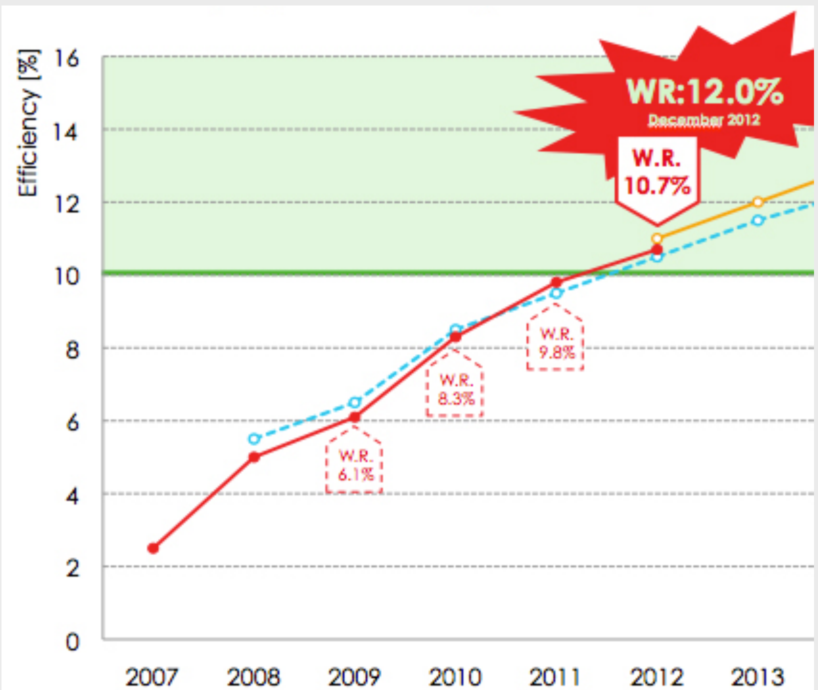
CdTe modules reach 16%

Crystalline Si won!

SunPower modules reach 24%

4. Huge Technology Shifts

Organic cells are coming!



HeliaTek:
Organic cells reach 12%

GaAs is coming!

PRESS RELEASE

March 4, 2013, 6:00 a.m. EST

Alta Devices Achieves 30.8% Efficiency Record with New Generation Solar Cell Technology

Will Enable Significant Battery Life Extension in Mobile and Consumer Devices

ALTADEVICES

Business Wire
A Berkshire Hathaway Company

SUNNYVALE, Calif., Mar 04, 2013 (BUSINESS WIRE) -- Alta Devices today disclosed that it has reached 30.8% solar cell efficiency. This new NREL (National Renewable

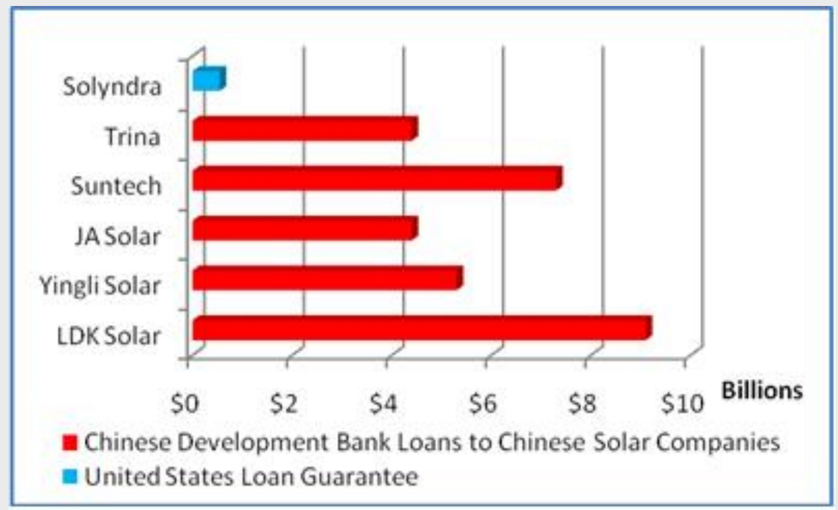
Alta Devices:
GaAs cells reach 27-30%

5. Huge Shifts in Government Subsidies

Shifting US preferences

Crystalline Si preferred in 2013

Non-US Solar Companies

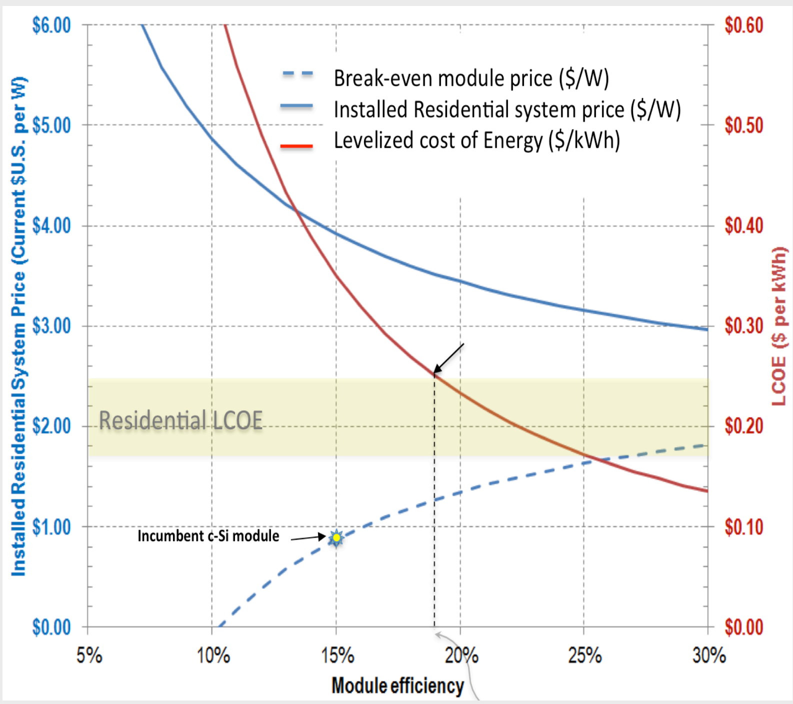


China: gov't loans key economic factors

Germany: tax subsidies key factors

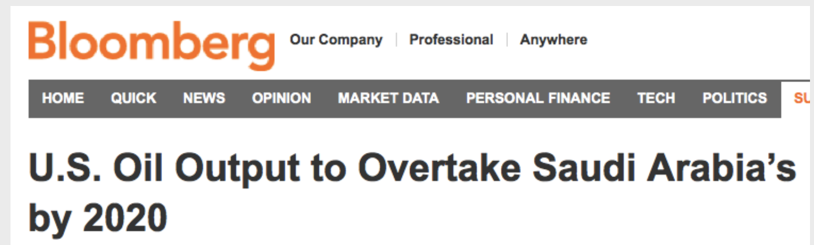
6. Huge Shifts in Competing Energy Sectors

Grid Parity at 1$/W



"Parity" reached in 2012: 0.72 $/W

Hydraulic Fracking changed everything in last 4 years



Expected grid parity shifted to 0.3$/W

Energy Research Strategies in such a Stormy World

"All of the above" strategy

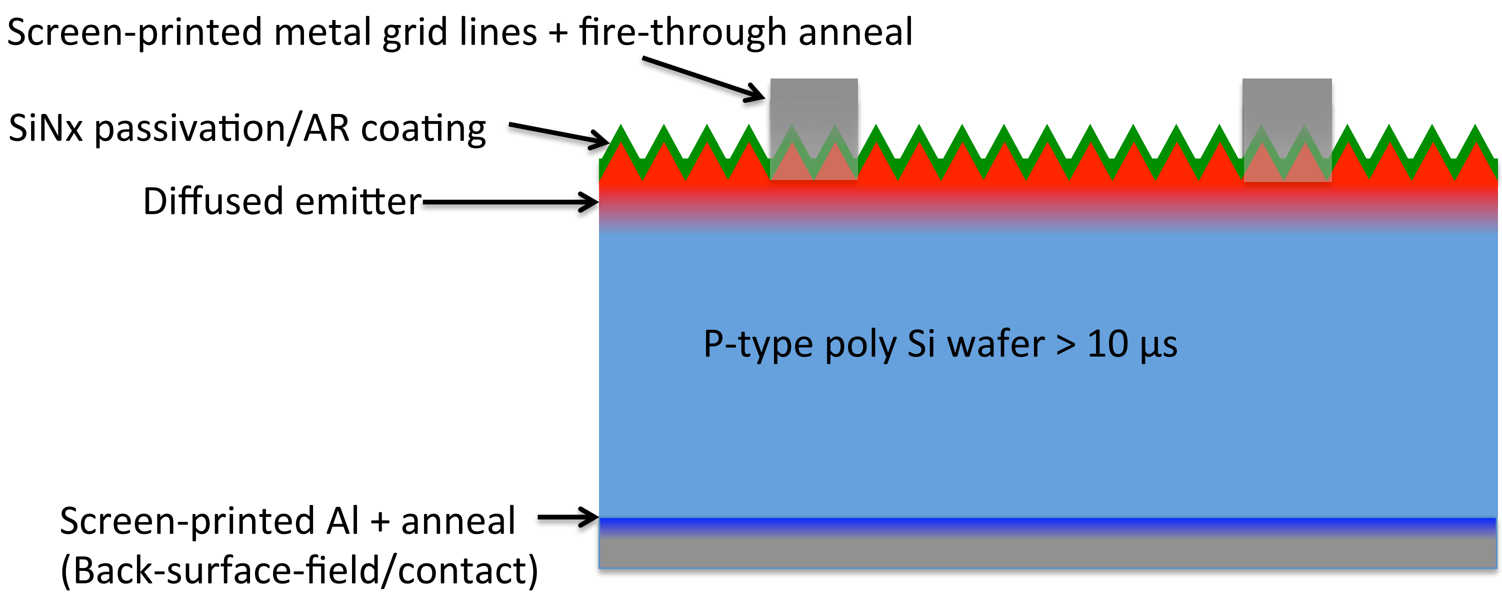
1. All of the above strategies need to be pushed
2. Time to think very differently, pursue radically new designs
3. But we have to accept that a primary guiding principle is the eventual utility of our research.

Advocacy – self-policing

1. The scientific community needs to advocate support this "all of the above" strategy
2. A baseline support needs to be secured for all directions to shelter them from the devastating fluctuations
3. Promise critical self-governance/ policing to prove that we are good guardians of the energy research effort

Frontiers

Standard c-Si cell



Efficiency: 15 – 17%

Can this cell design compete?

Advantages:

- Cheap (low-lifetime) wafers
- ~8 processing steps*
- Simple processing steps (one step emitter)
- SiNx and Al serve two functions each

Disadvantages:

- Diffused emitter is over doped causing high SRV in the emitter
- Metal front contact has high SRV
- Full back contact has high SRV

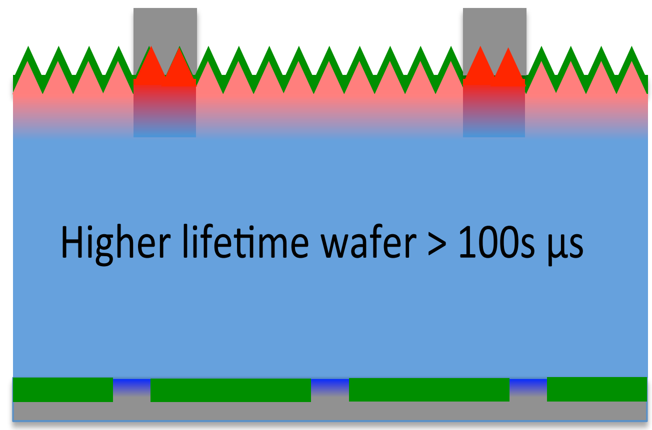
PERL c-Si cell

PERL= Passivated Emitter and Rear Locally diffused cell UNSW

Advantages:

- High Efficiency (current Si world record)
- Better Quantum Efficiency (Blue and Red)
- Optimized emitter and contacts separately

Efficiency > 20%



Disadvantages:

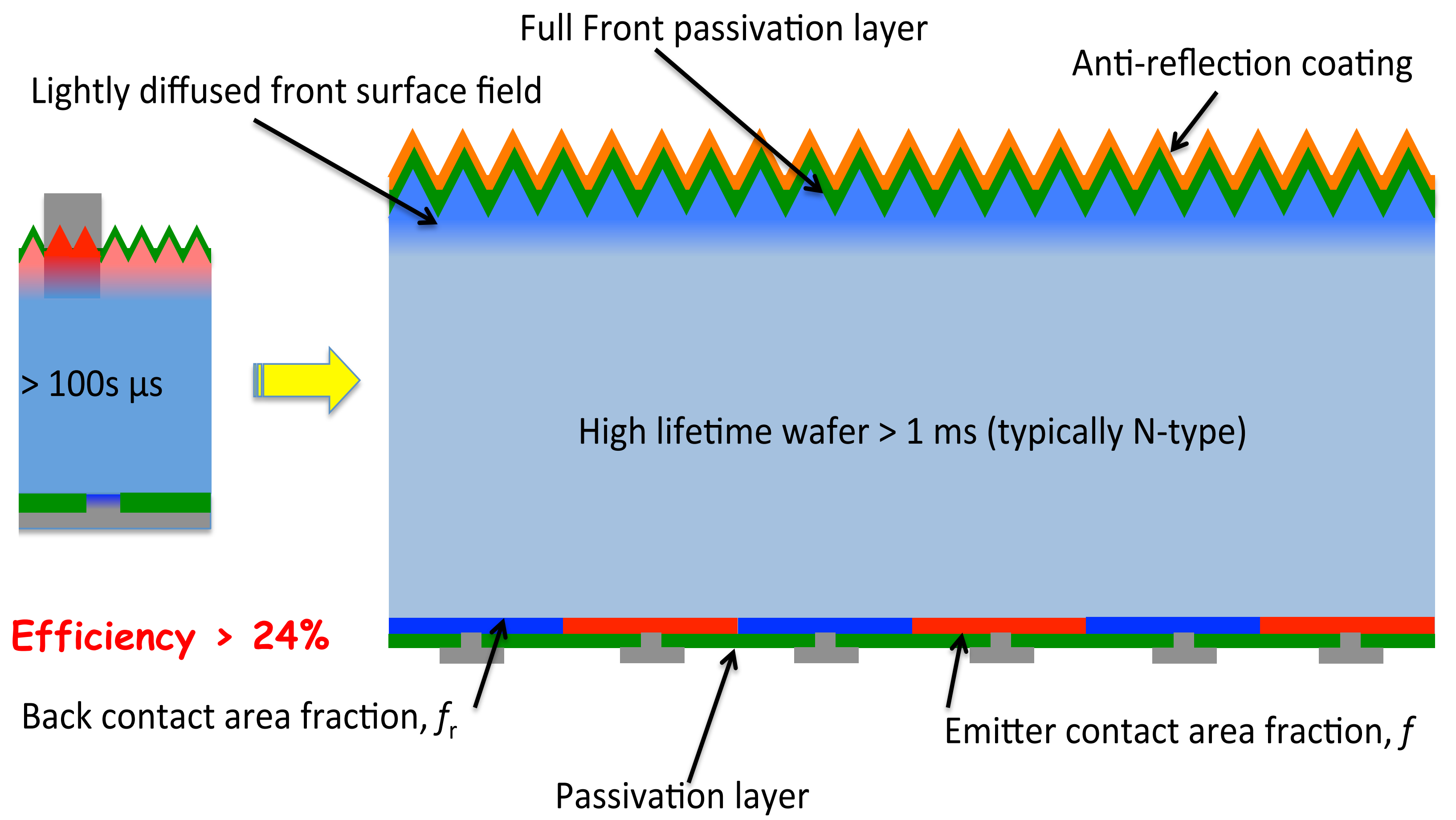
- Requires higher lifetime wafers
- ~ 12 process steps*
- Complicated mask alignment processing
- Front grid shading loss

Solutions:

- Move from p-type to n-type wafers
- Replace diffusion with Ion implantation
- Remove front grid

Inderdigitated Back Contact c-Si cell

SunPower cell

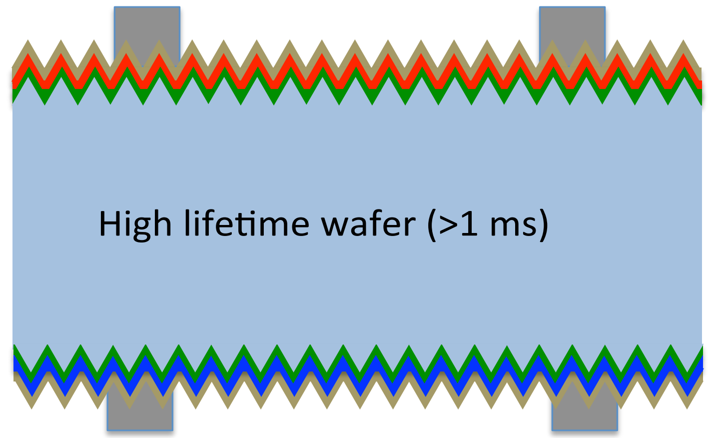


HIT: c-Si/a-Si Heterojunction Si cell

HIT: Sanyo/Panasonic cell

Advantages:

- High Efficiency design
- Full area passivated contacts (no metal-to-Si)
- Very high V_{oc}
- ~ 8 process steps
- Low-temperature processing (< 250 ˚C)
- No doping of wafer – maintains high lifetime
- Bifacial operation



Efficiency > 24.7%

Disadvantages:

- Process window may be narrow (small production)
- Very sensitive to cleaning
- Use of TCO is expensive
- TCO used for optical and electrical functions
- Reliability? (a-Si and TCO)
- Low Quantum Efficiency (absorpt. in TCO and doped a-Si)
- Requires low-temperature grid paste
- Process temperatures < 250 ˚C

Solutions:

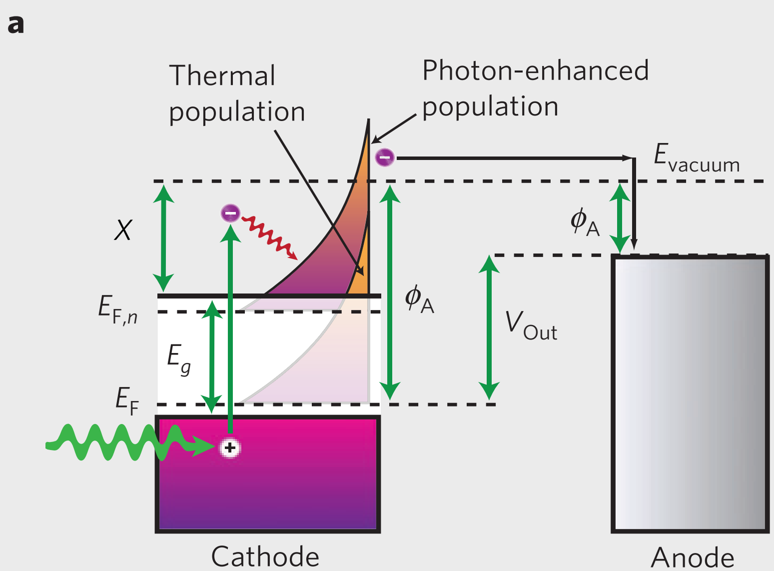
- Other passivated contact materials and processing schemes?

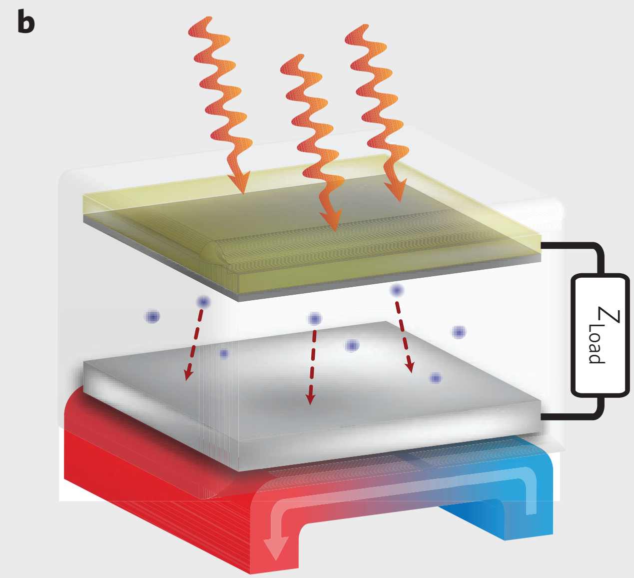
Si cells: Present Frontiers

- Switching from p-type to n-type single crystal wafers
- Selective area contacts
- Contact Passivation
- Tandem junction

Z.X. Shen (Stanford): Call me Pete

PETE: Photon Enhanced Thermionic Emission





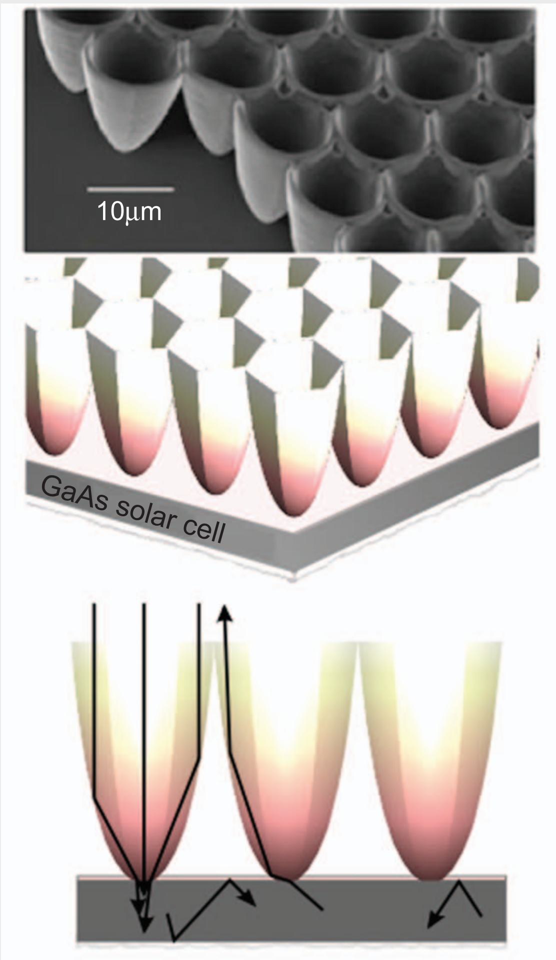
Uses all the bandgap energy +

the thermal energy for boosting emission:

Efficiency > 48% under concentration

Harry Atwater (CalTech): Photon management

Limiting re-emission angle



Balance with radiation field skewed:

Incoming radiation from narrow Sun disk

Re-emitted outgoing radiation to full spatial angle

Limiting re-emission angle improves balance:

Voc >1V, Efficiency > 33-35%